MULTI-CHANNEL ADAPATIVE QUALITY CONTROL LOOP FOR LINK RATE ADAPTATION IN DATA PACKET COMMUNICATIONS

RELATED APPLICATION

5   Related subject matter is disclosed in the following applications filed concurrently and assigned to the same assignee hereof: U.S. Patent Application Serial No. _____ entitled, "DELAY SENSITIVE ADAPATIVE QUALITY CONTROL LOOP FOR RATE ADAPTATION," inventors Sridhar Gollamudi and Pantelis Monogioudis; and U.S. Patent Application Serial No. _____ entitled, "ADAPATIVE QUALITY CONTROL

10   LOOP FOR RATE ADAPTATION IN DATA PACKET COMMUNICATION," inventors Sridhar Gollamudi and Pantelis Monogioudis.

FIELD OF THE INVENTION

The present invention relates generally to wireless data packet communications

15   and, in particular, to performing quality control for wireless data packet communications.

BACKGROUND OF THE RELATED ART

In data packet communications over time-varying wireless communication channels, rate adaptation may be used to optimize data transmission. Rate adaptation is a

20   technique that involves dynamically selecting a data rate for each packet of data to be transmitted based on a latest estimate of channel condition. The objective of rate adaptation is to select a data rate that would maximize data throughput without compromising data transmission quality.

In one rate adaptation proposal, selecting a data rate involves selecting a modulation and/or channel coding scheme, also referred to herein as "MCS level", and one or

25   more of spreading codes, such as orthogonal spreading codes, to use in the transmission of the data packet at the selected MCS level. That is, the data rate, denoted as $R(n,k)$, is a function of MCS level n and the number of spreading codes k used in a current transmission of a data packet at MCS level n. FIG. 5 depicts a chart 50 illustrating the relationship between data rate, MCS levels and spreading codes. Each MCS level n has associated a channel condition threshold $\theta(n)$

30   and one or more spreading codes, wherein the total number of spreading codes associated with a particular MCS level n is referred to herein as c_n and $k \leq c_n$. Low MCS levels are associated with lower order modulation and/or stronger channel coding schemes, whereas high MCS levels are associated with higher order modulation and/or weaker channel coding schemes. As the MCS level n and the number of spreading codes k increase, the data rate $R(n,k)$ increases.

The number of spreading codes k to be used in the current data packet transmission at the selected MCS level n is determined from a power offset given by a ratio of a channel quality metric to a channel condition threshold $\theta(n)$ associated with the selected MCS level n, as is known in the art. For example, $k = \lfloor 10^{power\ offset/10} \rfloor$, where the power offset can be

5   signaled from the receiver to the transmitter. The MCS level n is selected based on estimates of channel conditions between a receiver and a transmitter. Channel conditions between a transmitter and a receiver are estimated at the receiver using any channel quality metric, such as carrier to interference (C/I) ratio, signal to interference plus noise ratio (SINR) or Shannon capacity. The estimate of channel condition is subsequently relayed, via a feed back channel, to

10   the transmitter. The transmitter uses the estimate of channel condition to select an MCS level at which the transmitter is to transmit data packets to the receiver. In order to maximize data throughput, the MCS level n selected should be the MCS level n associated with the highest channel condition threshold $\theta(n)$ which the estimate of channel condition satisfies. A channel condition threshold is satisfied when the estimate of channel condition is greater or equal to the

15   channel condition threshold. In good channel conditions, data transmission quality is less likely to be affected, thus a higher MCS level may be selected to achieve a higher data rate. By contrast, in poor channel conditions, data transmission quality is more likely to be affected and a lower MCS level should be selected to provide greater protection for the data packet being transmitted. The number of spreading codes and the selected MCS level is communicated to the receiver by

20   the transmitter. Based on the number of spreading codes and the selected MCS level, the receiver would know which spreading codes and MCS level to use in decoding an associated transmitted data packet from the transmitter.

The choice of channel condition thresholds $\theta(n)$ can significantly affect link performance criteria, such as average throughput, packet and bit error rates and average number

25   of retransmissions with ARQ, HARQ or similar error correction schemes. Optimal choice of channel condition thresholds $\theta(n)$ are based on a complicated function of several factors such as metric estimation accuracy, Doppler frequency of the channel, feedback delay, fading statistics and SINR at the receiver, channel profile, choice of MCS levels, and transmitter and receiver design. Most of these factors are, however, time varying which would, in turn, cause the optimal

30   channel condition thresholds to be time varying. Thus, it would be desirable for channel condition thresholds $\theta(n)$ that are adaptive as the factors vary over time. One way of implementing adaptive channel condition thresholds $\theta(n)$ involves measuring the above mentioned factors in real-time and calculating optimized channel condition thresholds $\theta(n)$ based

on those factors. However, due to the large number of factors affecting the optimal channel condition thresholds $\theta(n)$, it would be impractical to implement channel condition thresholds $\theta(n)$ in this manner. Accordingly, there exists a need for adaptively selecting channel condition thresholds for rate adaptation using MCS levels and one or more spreading codes in real-time

5   without measuring all the factors that affect optimal channel condition thresholds.

SUMMARY OF THE INVENTION

The present invention is an adaptive quality control loop for link rate adaptation based on modulation and/or coding schemes (also referred to as "MCS levels") and one or more

10   spreading codes that adaptively selects channel condition thresholds in real-time without measuring all the factors that affect selecting optimal channel condition thresholds. The adaptive quality control loop involves adjusting the channel condition thresholds with variable up and down steps based on target quality metrics along with measurements such as error detection results, relative frequencies of visiting each MCS level, and transmitted data rates, wherein the

15   target quality metrics can be a block error rate or bit error rate target criterion. If the target quality metric is a block error rate target criterion, the variable step is determined using a desired MCS error rate based on MCS probabilities, MCS error rates and the block error rate target criterion. If the target quality metric is a bit error rate target criterion, the variable step is determined using a desired MCS error rate based on MCS probabilities, MCS error rates, average

20   rate of bit errors, data rate, and the bit error rate target criterion.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying

25   drawings where:

FIG. 1 depicts a wireless communication system used in accordance with the present invention;

FIG. 2 depicts a flowchart illustrative of an adaptive quality control loop in accordance with one embodiment of the present invention;

30   FIG. 3 depicts a flowchart illustrative of one embodiment of determining variable up steps $\Delta_{Up}(n)$ and down steps $\Delta_{Down}(n)$ using modulation and/or coding schemes (MCS) probabilities $P(n)$, MCS error rate $p(n)$ and a block error rate (BLER) target criterion;

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FIG. 4 depicts a flowchart illustrative of one embodiment of determining variable up steps $\Delta_{Up}(n)$ and down steps $\Delta_{Down}(n)$ using modulation and/or coding schemes (MCS) probabilities $P(n)$, MCS error rate $p(n)$ and a bit error rate (BER) target criterion; and

FIG. 5 depicts a chart illustrating relationships between data rate, MCS levels and

5   spreading codes.

DETAILED DESCRIPTION

The present invention is an adaptive quality control loop for link rate adaptation based on modulation and/or coding schemes (also referred to as "MCS levels") and one or more

10   spreading codes that adaptively selects channel condition thresholds in real-time without measuring all the factors that affect selecting optimal channel condition thresholds. The adaptive quality control loop involves adjusting the channel condition thresholds with variable up and down steps based on target quality metrics along with measurements such as error detection results, relative frequencies of visiting each MCS level, and transmitted data rates, wherein the

15   target quality metrics can be a block error rate or bit error rate target criterion.

FIG. 1 depicts a wireless communication system 10 used in accordance with the present invention. Wireless communication system 10 incorporates a multiplexing scheme, such as code division multiple access (CDMA), time division multiple access (TDMA), etc. Wireless communication system 10 comprises a transmitter 12 and a receiver 14. Transmitter 12 includes

20   a transceiver 16 for transmitting and receiving data over an air interface, and a processor 18 with associated memory 19 for determining a particular MCS level at which to transmit data packet. Receiver 14 includes a transceiver 20 for receiving and transmitting data over an air interface, a channel condition estimator 22 for estimating channel conditions between transmitter 12 and receiver 14, and an error detector 24 for detecting error in received data packet. Note that

25   processor 18 and memory 19 may, alternately, be parts of receiver 14 or of an independent entity in communication with both receiver 14 and transmitter 12. Thus, the present invention should not be limited to a wireless communication system in which processor 18 and memory 19 are parts of transmitter 12.

FIG. 2 depicts a flowchart 200 illustrative of an adaptive quality control loop in

30   accordance with one embodiment of the present invention. In step 205, transmitter 12 transmits a signal, wherein the signal may be any signal which channel condition estimator 22 can use to estimate channel conditions between transmitter 12 and receiver 14, such as a pilot signal or beacon frequency signal. In step 210, receiver 14 receives the signal and channel condition estimator 22 estimates the channel condition between transmitter 12 and receiver 14 using the

received signal. Channel conditions can be estimated using any channel quality metric, such as carrier to interference (C/I) ratio, signal to interference plus noise ratio (SINR) or Shannon capacity. The estimate of channel condition is transmitted by receiver 14, in step 215, over a feedback channel to transmitter 12.

5   In step 220, transmitter 12 receives the estimate of channel condition and processor 18 uses such estimate to determine a current MCS level m and a number of spreading codes k for transmitting a data packet to receiver 14 at the current MCS level m. The current MCS level m may be selected from a look-up table. In the look-up table, each MCS level n has associated a channel condition threshold $\theta(n)$ and one or more spreading codes, wherein the total

10   number of spreading codes associated with a particular MCS level n is referred to herein as c_n and $k \leq c_n$. Low MCS levels are associated with strong modulation and/or channel coding schemes, whereas high MCS levels are associated with weak modulation and/or channel coding schemes. As the MCS level n and the number of spreading codes k increase, the data rate $R(n,k)$ increases. Channel condition threshold $\theta(n)$ may, in one embodiment, be initially determined based on a

15   complex function of several factors such as metric estimation accuracy, Doppler frequency of the channel, feedback delay, fading statistics and SINR at the receiver, channel profile, choice of MCS levels, and transmitter and receiver design, as is well-known in the art.

The MCS level n is selected based on the estimate of channel condition. In order to maximize data throughput, the current MCS level m selected should be the MCS level n

20   associated with the highest channel condition threshold $\theta(n)$ which the estimate of channel condition satisfies. A channel condition threshold is satisfied when the estimate of channel condition is greater or equal to the channel condition threshold. In good channel conditions, data transmission quality is less likely to be affected, thus a higher MCS level may be selected to achieve a higher data rate. By contrast, in poor channel conditions, data transmission quality is

25   more likely to be affected and a lower MCS level should be selected to provide greater protection for the data packet being transmitted.

The number of spreading codes k to be used in the current data packet transmission at the current MCS level m is determined from a power offset given by a ratio of a channel quality metric to channel condition threshold $\theta(m)$ associated with the current MCS level

30   m. In step 223, transmitter 12 communicates the current MCS level m and the determined number of spreading codes k to receiver 14. Based on the number of spreading codes, receiver 14 will know which spreading codes to use in decoding an associated data packet. Alternately, transmitter 12 communicates identities of the spreading codes to be used in the transmission of

the associated data packet. Note that in another embodiment, the current MCS level m and the number of spreading codes k is determined at receiver 14 and communicated to transmitter 12.

In step 225, transmitter 12 transmits data packet to receiver 14 using the current MCS level m and k number of spreading codes. In step 230, receiver 14 receives the data packet.

5   In step 235, error detector 24 determines whether the data packet transmission was successful, i.e., data packet could be successfully decoded at receiver 14 to obtain an error detection result. In one embodiment, error detector 24 performs a cyclical redundancy check (CRC) on the data packet, as is well-known in the art. If the CRC is successful, then error detector 24 determines that the error detection result is positive, i.e., data packet transmission was successful. If the CRC

10   fails, then error detector 24 determines that the error detection result is negative, i.e., data packet transmission failed.

If error detector 24 detects a successful data packet transmission, then receiver 14 transmits a success indicator over the feedback channel (or some other communication channel) to transmitter 12 indicating a positive error detection result, in step 240. If error detector 24

15   detects a failed data packet transmission, then receiver 14 transmits a failure indicator over the feedback channel (or some other communication channel) to transmitter 12 indicating a negative error detection result, in step 245.

From step 240 or 245, flowchart 200 proceeds to step 250 where processor 18 updates channel condition threshold $\theta(m)$ and, perhaps, channel condition thresholds $\theta(m)$ in the

20   table in memory 19 before returning to step 205. Note that a re-transmission of a data packet may occur at a MCS level different from the preceding transmission of the same data packet if the channel condition changes.

Updating channel condition threshold $\theta(m)$ (or other channel condition thresholds $\theta(n)$) involves the following. Generally, if a success indicator is received, the channel condition

25   threshold $\theta(m)$ associated with the current MCS level m is decreased a down step $\Delta_{Down}(m)$, i.e., the channel condition threshold $\theta(m)$ is lowered. By contrast, if a failure indicator is received, the channel condition threshold $\theta(m)$ associated with the current MCS level m is increased an up step $\Delta_{Up}(m)$, i.e., the channel condition threshold $\theta(m)$ is increased. Other embodiments for updating channel condition thresholds $\theta(m)$ (or other channel condition thresholds $\theta(n)$) are described later

30   herein.

In addition to adjusting the channel condition threshold $\theta(m)$ of the current MCS level m, the channel condition thresholds $\theta(n)$ of other MCS levels n may also be adjusted, as will be described herein. Note that, when increasing or decreasing channel condition thresholds $\theta(n)$,

the channel condition thresholds being increased or decreased should not be increased above or decreased below their adjacent channel condition thresholds. That is, for example, channel condition threshold $\theta(2)$ should not be decreased below channel condition threshold $\theta(1)$ nor increased above channel condition threshold $\theta(3)$.

5   Many variations of the up step Δ_{Up} and down step Δ_{Down} may exist for the present invention. Some of these variations will be described herein. This should not, however, be construed to be inclusive of all possible variations of up steps Δ_{Up} and down steps Δ_{Down} for the present invention. The down step Δ_{Down} (m) for channel condition threshold $\theta(m)$ may be equal to or different from the up step Δ_{Up} (m) for the same channel condition threshold $\theta(m)$.

10   The up step Δ_{Up} (n) and down step Δ_{Down} may be the same, different or some combination thereof across all channel condition thresholds $\theta(n)$. For example, the up step Δ_{Up} (1) for channel condition threshold $\theta(1)$ may be the same or different than the up step Δ_{Up} (2) for channel condition threshold $\theta(2)$.

The up steps Δ_{Up} (n) and down steps Δ_{Down} (n) may be of fixed or variable sizes
15   for a particular or all channel condition thresholds $\theta(n)$. In one embodiment, channel condition thresholds $\theta(n)$ are adaptively adjusted using variable up steps Δ_{Up} (n) and down steps Δ_{Down} (n). The variable up steps Δ_{Up} (n) and down steps Δ_{Down} (n) may be determined in a variety of manners. Two manners are proposed herein. The first manner of determining variable up steps Δ_{Up} (n) and down steps Δ_{Down} (n) is based on block error rate (BLER) P_{BLER}, which is a rate of
20   data packet error averaged over all MCS levels. The second manner is based on bit error rate (BER) P_{BER}, which is a rate of bit error averaged over all MCS levels.

The first manner is illustrated in FIG. 3, which depicts a flowchart 300 for determining variable up steps Δ_{Up} (n) and down steps Δ_{Down} (n) using MCS probabilities P(n), MCS error rates p(n), and a BLER target criterion. The MCS probability P(n) is the probability
25   that a data packet is transmitted with MCS level n to a particular receiver. In other words, it is the fraction of times that MCS level n is selected for data packet transmission to a particular receiver. The MCS error rate p(n) is the probability that a data packet transmitted using MCS level n would not be received successfully by a particular receiver

In step 305, MCS probabilities P(n) for MCS levels n for receiver 14 are updated
30   using the current MCS level m. In one embodiment, MCS probabilities P(n) are estimated using

simple averaging. For example, suppose there are three MCS levels 1, 2 and 3, and MCS levels

1, 2 and 3 were chosen 3, 4 and 2 times, respectively, prior to choosing the current MCS level m.

The MCS probabilities prior to the selection of the current MCS level m would then be estimated

to be P(1) = 0.33, P(2) = 0.44 and P(3) = 0.22. If the current MCS level m is 1, then the MCS

5   probabilities P(n) would be updated such that P(1) = 0.40, P(2) = 0.40 and P(3) = 0.20.

In another embodiment, MCS probabilities P(n) are estimated using exponential

averaging. Specifically, the MCS probabilities P(n) are estimated using equation (1),

$$P(n) = \begin{cases} \lambda P'(n) + (1-\lambda) & \text{if } n = m \\ \lambda P'(n) & \text{otherwise} \end{cases} \qquad \text{equation (1)}$$

where λ is a forgetting factor that is between 0 and 1 (usually closer to 1) and prime ' indicates

10   the previous value of the associated parameter prior to update. The forgetting factor is a factor

used to compute an average of a sequence of observations when the average itself is a slowly

varying quantity, as is well-known in the art. The MCS probabilities P(n) may be estimated using

other averaging schemes, such as computing an average over a sliding window. Thus, the present

invention should not be limited to the above described techniques for estimating MCS

15   probabilities P(n).

In step 310, MCS error rate p(m) for the current MCS level m is estimated. In

one embodiment, MCS error rate P(m) is estimated using simple averaging. For example, if 50%

of the data packet sent with MCS level 3 have CRC failures, then the MCS error rate for level 3 is

p(3) = 0.5. In another embodiment, MCS error rate p(m) is estimated using exponential

20   averaging. Specifically, MCS error rate p(m) is estimated using equation (2).

$$p(m) = \begin{cases} \lambda p'(m) + (1-\lambda) & \text{if CRC fails} \\ \lambda p'(m) & \text{if CRC succeeds} \end{cases} \qquad \text{equation (2)}$$

The MCS error rate p(m) may be estimated using other averaging schemes, such as computing an

average over a sliding window. Thus, the present invention should not be limited to the above

described techniques for estimating the MCS error rate p(m). Note that, in step 310, only the

25   MCS error rate p(m) for the current MCS level m is estimated, and not MCS error rate p(n) for all

MCS levels n. The reason for not updating the MCS error rate p(n) for other MCS levels n is

because no new information is available at this time for the other MCS levels n. It should be

understood that estimates for MCS error rates p(n) of MCS levels n other than MCS level m also

exist.

30   In step 315, a desired MCS error rate p(m), denoted hereinafter as $p_d(m)$, is

computed for current MCS level m. The desired MCS error rate $p_d(m)$ is based on a BLER target

criterion, referred to herein as P_{BLER}^{Target}, which is a target or desired P_{BLER} averaged over all MCS

levels n. Note that P_{BLER} can generally be expressed using equation (3),

$$P_{BLER} = \sum_{n=1}^{M} p(n)P(n) \qquad \text{equation (3)}$$

where M is the total number of MCS levels.

5   The desired MCS error rate $p_d(m)$ is determined using equation (4).

$$p_d(m) = \frac{1}{P(m)}\left[P_{BLER}^{Target} - \sum_{n=1,n \neq m}^{M} p(n)P(n)\right] \qquad \text{equation (4)}$$

In step 320, the desired MCS error rate $p_d(m)$ is used to determine the sizes or a

ratio between the sizes of the down step $\Delta_{Down}(m)$ and up step $\Delta_{Up}(m)$ for the current MCS level

10   m. In one embodiment, the up-to-down step ratio for the current MCS level m is set to satisfy

equation (5).

$$\frac{\Delta_{Up}(m)}{\Delta_{Down}(m)} = \frac{1-p_d(m)}{p_d(m)} \qquad \text{equation (5)}$$

Alternatively, the sizes for the up step Δ_{Up} and down step Δ_{Down} may be determined using

equations (6) and (7), respectively:

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$$\Delta_{Up}(m) = \mu\left(1-p_d(m)\right) \qquad \text{equation (6)}$$

$$\Delta_{Down}(m) = \mu p_d(m) \qquad \text{equation (7)}$$

where μ is a positive constant.

The up and down steps Δ_{Up} and Δ_{Down} are used accordingly in step 250 to adjust

the corresponding channel condition threshold $\theta(m)$. That is, if a success indicator is received,

20   the channel condition threshold $\theta(m)$ is decreased a down step $\Delta_{Down}(m)$. If a failure indicator is

received, the channel condition threshold $\theta(m)$ associated with the current MCS level m is

increased an up step $\Delta_{Up}(m)$.

The second manner of determining variable up steps $\Delta_{Up}(n)$ and down

steps $\Delta_{Down}(n)$ is illustrated in FIG. 4, which depicts a flowchart 400 that uses MCS probabilities

25   P(n), MCS error rates p(n), and a BER target criterion to determine the variable up steps $\Delta_{Up}(n)$

and down steps $\Delta_{Down}(n)$. In step 405, MCS probabilities P(n) for receiver 14 are updated using

the current MCS level m in a manner similar to that described for step 305. In step 410, an estimate of an average transmitted data rate at the current MCS level m, denoted herein as $R(m)$, is updated. The average transmitted data rate for current MCS level m is updated, in one embodiment, using equation (8),

$$R(m) = \lambda R'(m) + (1-\lambda)R(m,k) \qquad \text{equation (8)}$$

where $R(m,k)$ is the data rate corresponding to k number of spreading codes used at the current MCS level m to transmit the current data packet. Note that estimates of average transmitted data rates at MCS levels $n \neq m$ are not updated.

In step 415, an estimate of average rate of bit errors, denoted $X(m)$, is updated for the current MCS level m using equation (9),

$$X(m) = \lambda X'(m) + (1-\lambda)X(m,k)B_e \qquad \text{equation (9)}$$

where B_e is 0 if CRC succeeds and 1 if CRC fails.

In step 420, a desired MCS error rate $p_d(m)$ is computed for current MCS level m. The desired MCS error rate $p_d(m)$ is based on a BER target criterion, referred to herein as P_{BER}^{Target}, which is a target or desired P_{BER} averaged over all MCS levels n. Note that P_{BER} can generally be expressed using equation (10),

$$P_{BER} = \frac{\displaystyle\sum_{n=1}^{M} X(n)P(n)}{\displaystyle\sum_{n=1}^{M} R(n)P(n)} \qquad \text{equation (10)}$$

where $R(n)$ is the average transmitted data rate for MCS level n. The desired MCS error rate $p_d(m)$ is determined using equation (11).

$$p_d(m) = \frac{1}{R(m)P(m)}\left[P_{BER}^{Target} \sum_{n=1}^{M} R(n)P(n) - \sum_{n=1, n \neq m}^{M} X(n)P(n) \right] \qquad \text{equation (11)}$$

In step 425, the desired MCS error rate $p_d(m)$ is used to determine the sizes or a ratio between the sizes of the down step down step $\Delta_{Down}(m)$ and up step $\Delta_{Up}(m)$ for the current MCS level m in a manner similar to step 320.

The up step $\Delta_{Up}(m)$ and down step $\Delta_{Down}(m)$ are used accordingly in step 250 to adjust the corresponding channel condition threshold $\theta(m)$. In one embodiment, when a target BER is used, the channel condition threshold $\theta(m)$ for the current MCS level m is adjusted in step 250 according to equation (12),

$$\theta(m)=\begin{cases} \theta'(m)+\delta(m)R(m,k)\Delta_{Up}(m) & \text{if CRC fails} \\ \theta'(m)-\delta(m)R(m,k)\Delta_{Down}(m) & \text{if CRC succeeds} \end{cases} \qquad \text{equation (12)}$$

where $\delta(m)$ is a small fixed positive constant for MCS level m.

In one embodiment, only the channel condition threshold $\theta(m)$ for the current

MCS level m is adjusted in step 250. In another embodiment, one or more other channel

5   condition thresholds $\theta(n)$ for MCS levels n other than MCS level m are also adjusted. For

example, the other channel condition thresholds $\theta(n)$ being adjusted are adjusted the same amount

as channel condition threshold $\theta(m)$ such that the relative distance between the channel condition

thresholds $\theta(n)$ being adjusted, including channel condition threshold $\theta(m)$, remain fixed.

Alternately, the other channel condition thresholds $\theta(n)$ are adjusted using up steps $\Delta_{Up}(n)$ and

10   down steps $\Delta_{Down}(n)$ determined separately from up step $\Delta_{Up}(m)$ and down step $\Delta_{Down}(m)$.

In one embodiment of determining the sizes of the variable up steps $\Delta_{Up}(n)$ and

down steps $\Delta_{Down}(n)$ where the relative positions of the channel condition thresholds are

unchanged, i.e., if at every update instant the same up and down steps are applied to all

thresholds, the variable up steps $\Delta_{Up}(n)$ and down steps $\Delta_{Down}(n)$ are determined based a

15   constant target BER P_{BER}^{Target} and data rates $R(n)$ using equations (13) and (14).

$$\Delta_{Up}(n) = \mu R(n)\left(1 - P_{BER}^{Target}\right) \qquad \text{equation (13)}$$

$$\Delta_{Down}(n) = \mu R(n)P_{BER}^{Target} \qquad \text{equation (14)}$$

Note that the target BLER P_{BLER}^{Target} may be used instead of the target BER P_{BER}^{Target} to determine the

sizes for the up step $\Delta_{Up}(n)$ and down step $\Delta_{Down}(n)$ in step 320 of flowchart 300.

20   The present invention has been described herein with reference to certain embodiment.

This should not be construed to limit the present invention to the embodiments described herein.

For example, the flowcharts depict an exact sequence of steps for use in the present invention.

The sequence of steps may vary such as, in another embodiment of flowchart 200, steps 205, 210,

215 and 220 may be executed as a part of steps 225, 230-235, 240-245 and 250, respectively.

25   Therefore, the spirit and scope of the present invention should not be limited to the description of

the embodiments contained herein.